Recurring Slope Lineae: Mobility Systems Analysis

IEEE Aerospace Conference
03/09/2018

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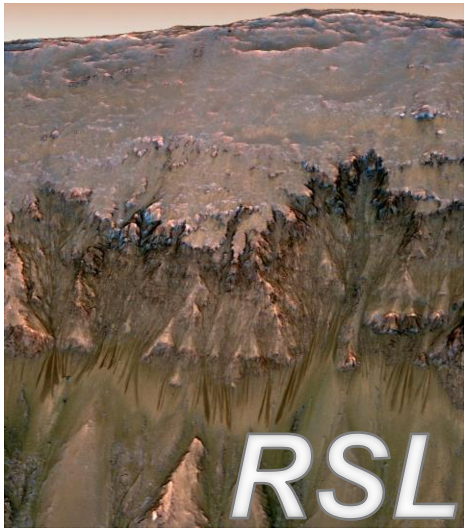
Outline

1. Background and Hypotheses	What is an RSL and why is understanding them important?
2. Landable RSL Sites	What are the landing requirements and how many RSL are feasibly landable?
3. Crater Descriptions and Mobility Challenges	Geometry, viewshed, terrain
4. Viable Solutions	Summary of trade space architectures; concept benefits and challenges
5. Trades, Rankings, and Future Work	Ranking matrix description, summary, and next steps

Understanding RSL

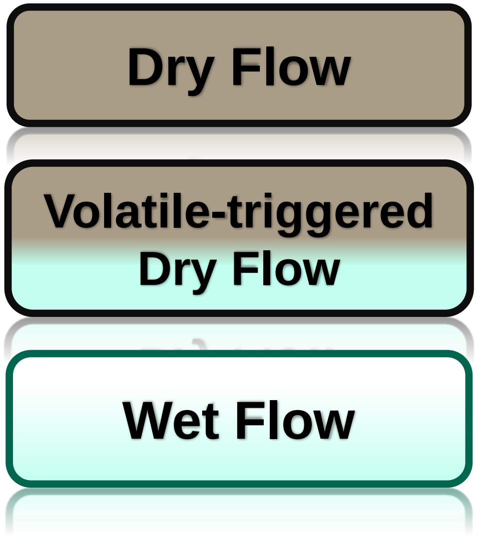


Definition:

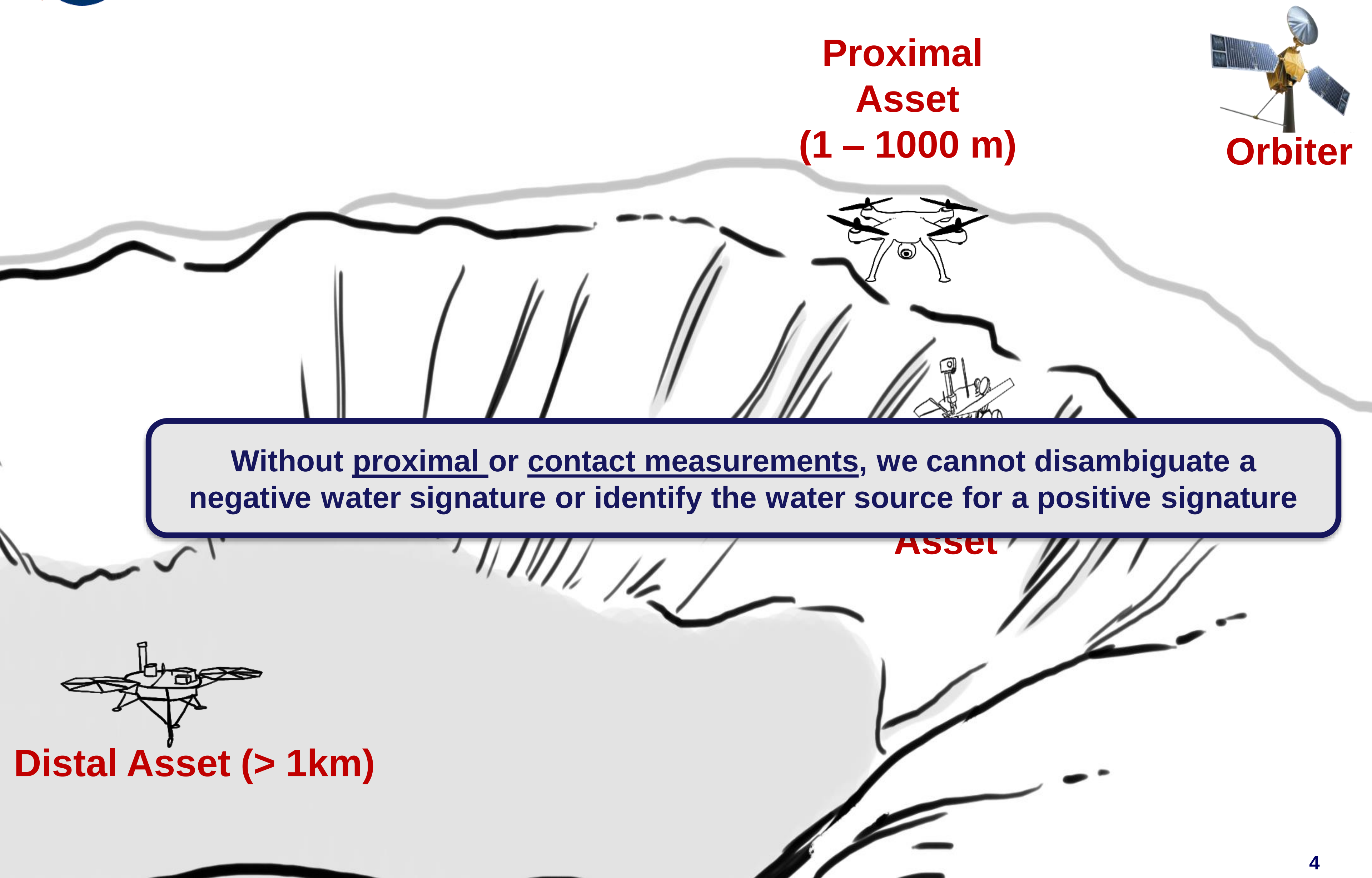
- Recurring Slope Lineae, RSL, are visible streaks observed on the faces of *some* craters and other steep landforms.
    1. Occur periodically
    2. Lengthen as a function of time
    3. Fade
- Dry flows, triggered by dust devils, impacts, or seismic events are not RSL

Provenance Hypotheses:

1. Dry Flow
2. Volatile-triggered Dry Flow
    a) CO_2 triggered
    b) H_2O triggered
3. Wet Flow
    a) Deliquescence (salts absorb atmospheric water)
    b) Shallow source (e.g. melting of near-surface ice)
    c) Deep source (e.g. ground water release from aquifer)

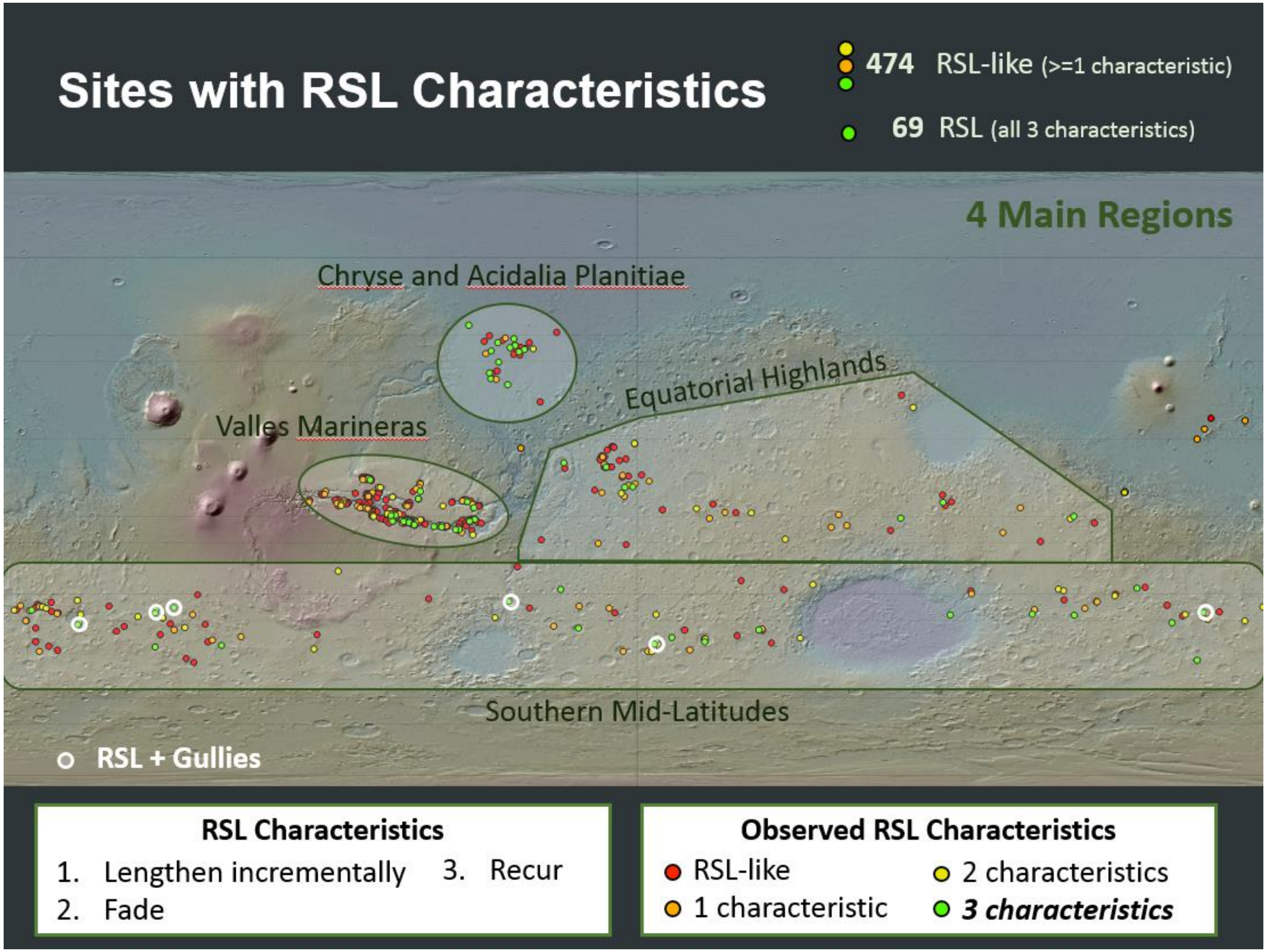


Disambiguation of Hypotheses: Strategy



Without <u>proximal</u> or <u>contact measurements</u>, we cannot disambiguate a negative water signature or identify the water source for a positive signature

Identified RSL



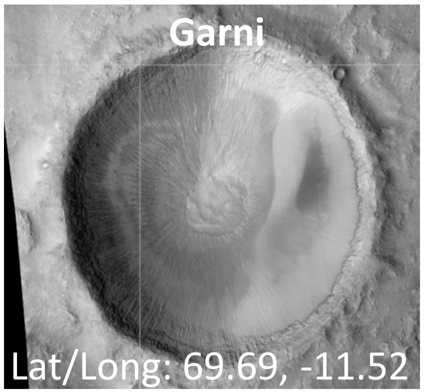
Identification of Promising Sites

Sites with Landing Constraints

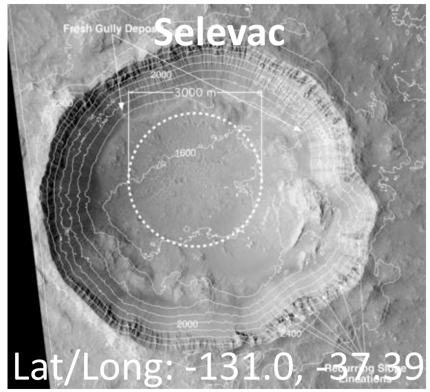
33 RSL Accessible with M2020 Landing

#	Name	Longitude	Latitude	Stereo	DTM	# Images	Context	Landable
1	**Midlatitudes 1**	318.10	28.66	N	N	8	2 km crater; craters everywhere, otherwise flat	Maybe
3	**Midlatitudes 3**	323.17	25.39	Y	N	14	1.4 km crater, secondaries everywhere	Maybe
7	**Meridiani 3**	358.53	-3.40	N	N	8	3 km crater	Yes
8	**Meridiani 4**	356.25	-3.51	N	N	8	950m crater; great flat lava	Yes
13	**Garni Crater**	290.31	-11.52	Y	Y	50	2.3 km crater; only top landing	Yes
31	**Valles 22**	304.57	-14.75	Y	Y	38	Mid-valles possible flat valley ellipse	Yes
34	**Andapa**	355.29	-5.26	N	N	11	9.5 km crater (did not recur yet)	Yes
36	**Selevac**	-131.06	-37.38	Y	N	56	7 km crater; rough ejecta; roving required	Maybe

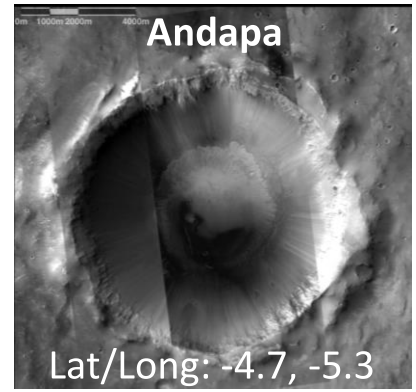
Study Focus Craters



Feature for Traverse Route
Average wall slope: ~27°
Max wall slope: ~40°
Minimum distance to RSL: 400 m↑, 250 m↓
Terrain: Polygonal ripples, dunes, bedrock, outcrop

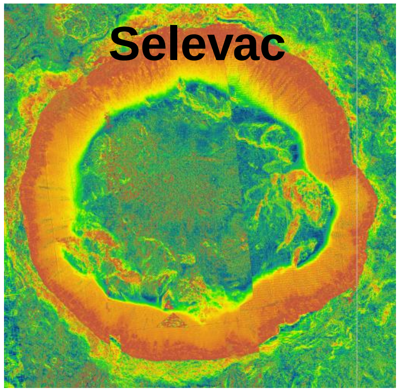


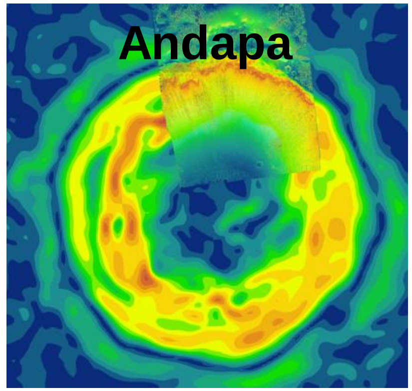
Feature for Traverse Route
Average wall slope: ~30°
Max wall slope: ~40°
Minimum distance to RSL: 600 m↑, 170 m↓
Terrain: Boulder field, loose sand, bedrock, outcrop

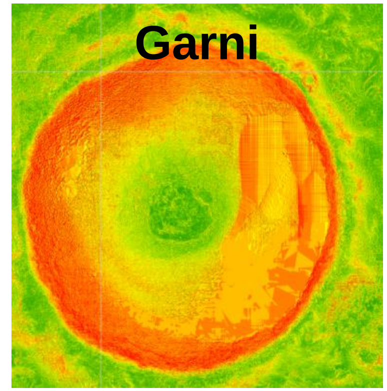


Feature for Traverse Route
Average wall slope: ~24°
Max wall slope: ~35°
Minimum distance to RSL: 1,200 m↑, 360 m↓
Terrain: Loose sand, bedrock, outcrop

Principal Mobility Challenges: Roughness and Slope







Blue≤ 9 degrees
10 degrees ≤ Green≤ 18 degrees
19 degrees ≤ Yellow≤ 27 degrees
27 degrees ≤ Orange≤ 36 degrees
Red ≥ 36 degrees

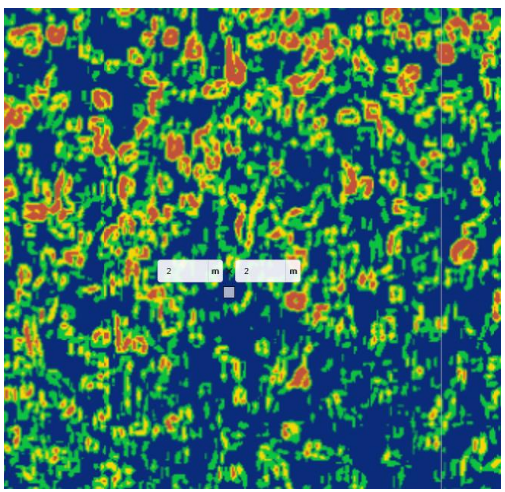
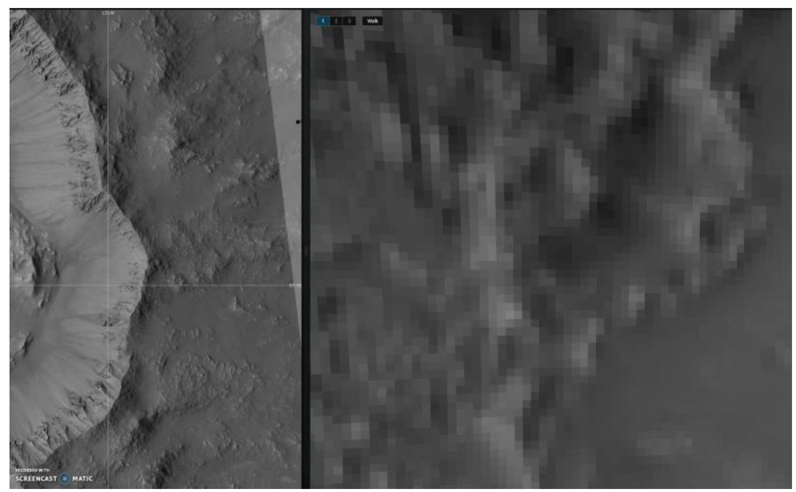


Fig: Boulder field. Square shows approximate footprint of Curiosity rover



Video: Video created in JPL WebGIS tool using 25 cm/p HiRISE imagery. DEM created at ~ 1 m/p. Shows: Ascent of crater rim, descent into crater over ~ 1 km traverse distance

Mobility System Categories

Approximately 30 concepts of operations (CONOPS) considered that broadly fit into the following 6 categories:

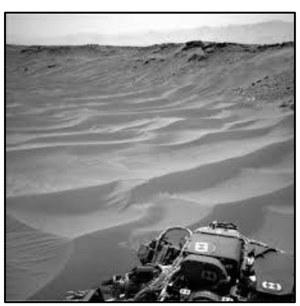
A. Ground Ascent (crater only)
B. Ground Descent (rim only)
C. Balloon (Not discussed; feasible)
D. Helicopter (both crater and rim)
E. Missile (both crater and rim)
F. Tether Riders (Not discussed; likely infeasible)

Ground Ascent

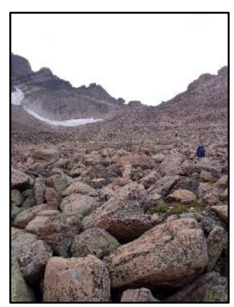
Pros	Cons
1. Provides good vantage	1. Terrain-dependent mobility system design
2. Heritage (higher starting TRL)	2. Terrain properties uncertainty
3. Large payload carrying capacity	3. Slip, entrenchment, static stability risks
4. Multiple measurement locations	4. Moderate risk of altering measurement site (avalanche)

Technologies/techniques considered

1. Wheeled
2. Tracked
3. Climbing (limbed, gecko grippers)
4. Walking
5. Push-roll
6. Variable normal force (air assisted)
7. Hopping
8. Electrostatic adhesion



Sand-filled crater floor. Ripples and dunes present.



Boulder fields

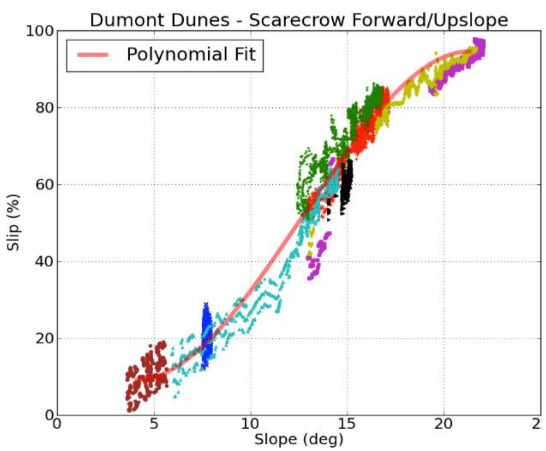
Unconsolidated granular media

Ascending Unconsolidated Slopes

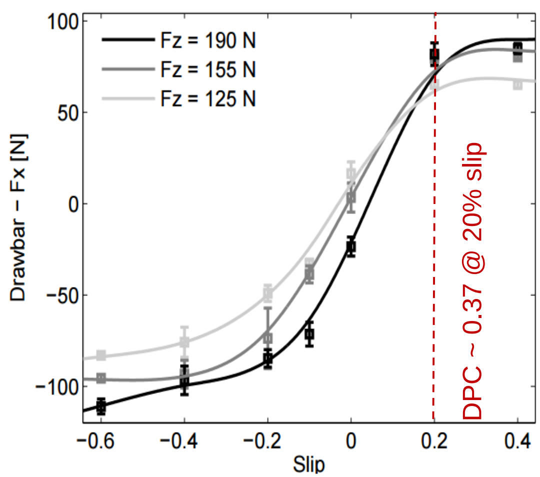
Rule of Thumb:
The slope a vehicle can ascend may be approximated as the arctangent of its Drawbar Pull Coefficient:

$$\theta = \tan^{-1}(DPC)$$

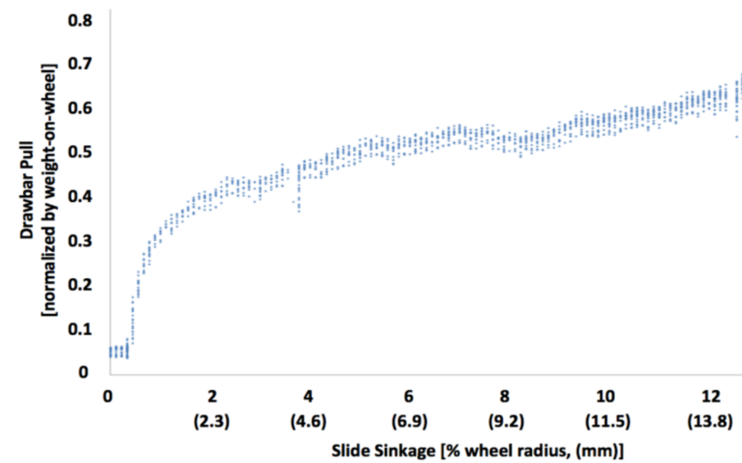
A 35° slope would require a DPC of 0.7, approximately 3X that of MSL/MER/M2020 at 20% slip



Curiosity slope climbing performance. Heverly et al., JFR, 2013, 10.1002/rob.21481



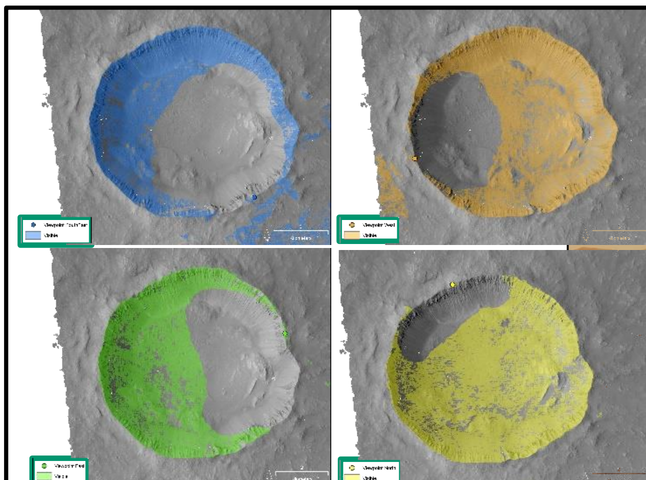
Lightweight tracked vehicle slope climbing performance. Senatore and Iagnemma, ISTVS, 2013



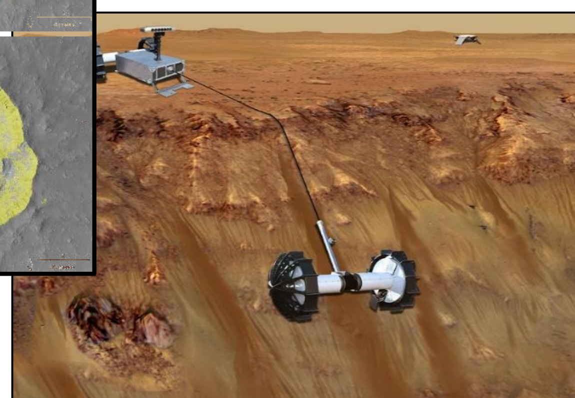
Push-roll locomotion using SCARAB rover. Moreland, Creager et al, CMU.

Rim Descent

Pros	Cons
1. Controlled descent with precise placement 2. Capable of carrying high-mass payloads 3. Multi-site measurements enabled 4. Reduced terrain-dependence and risk	1. Tether management on rough terrain 2. Somewhat reduced viewshed prior to entry

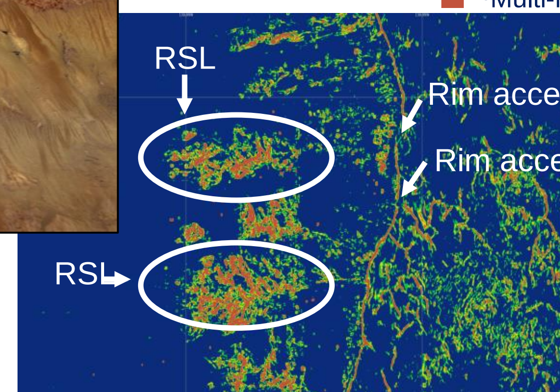


Viewshed analysis for rim-descent options. While 90 – 100 % of the crater wall is visible from inside the crater, 60 – 75% remains visible from the rim



JPL Axel rover concept art during descent into an RSL-bearing crater

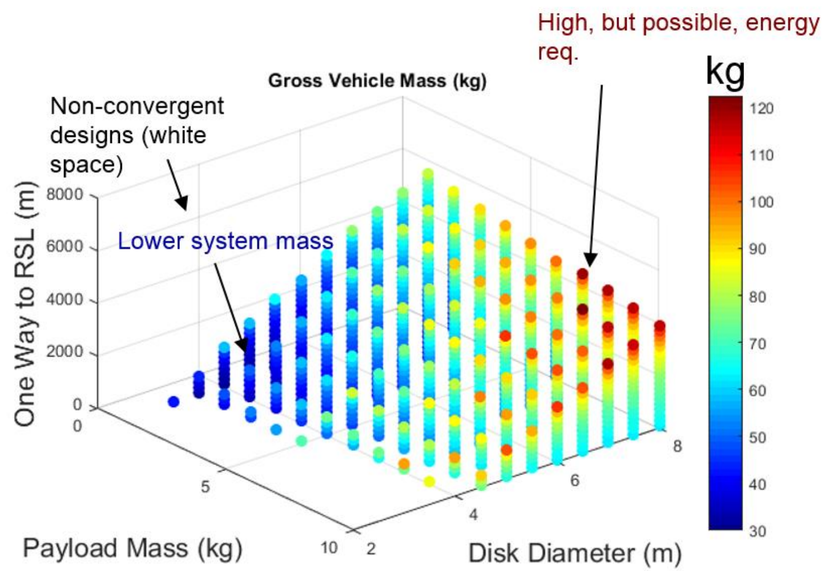
- ~Flat
- ~Decimeter scale
- ~Meter scale
- ~Multi-meter scale



Typical Crater rim roughness with challenges to tether management

Helicopter

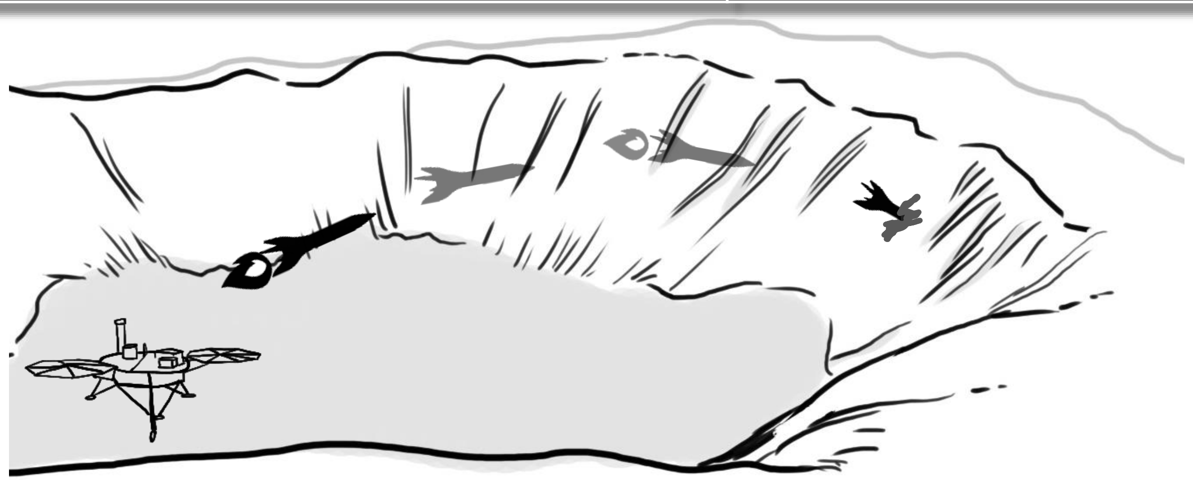
Pros	Cons
1. Lower complexity (fewer assets) than rover-based delivery option 2. Reduces control concerns during close approach to crater wall 3. Provides improved view-shed prior to aerial deployment	1. Helicopter scaling on Mars is not well understood 2. Control of helicopter + pendulum dynamics 3. Up to 8 km flight each way from lander on a single charge 4. Large mass and diameter for helicopter 5. Longer longer tether for payload deployment 6. Tether and winching mechanism mass reduces payload capacity



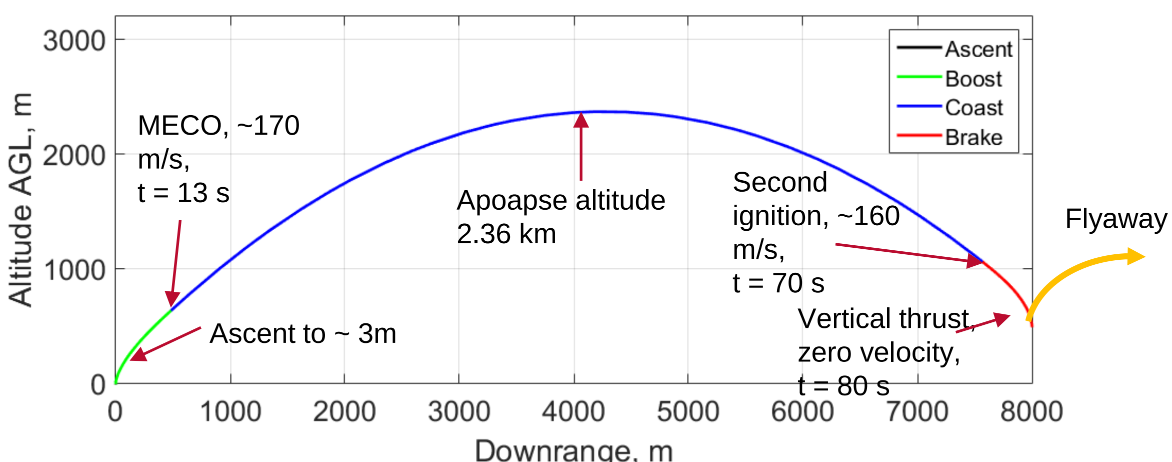
Gross Vehicle Mass

Missiles

Pros	Cons
1. Obviates need to scale crater wall 2. Rapid approach 3. Less subject to weather events (wind)	1. Significant disruption of measurement site 2. High loads on payload and subsystems 3. Assumes *a-priori* knowledge of surface strength 4. Requires consumables 5. Accuracy may be limited

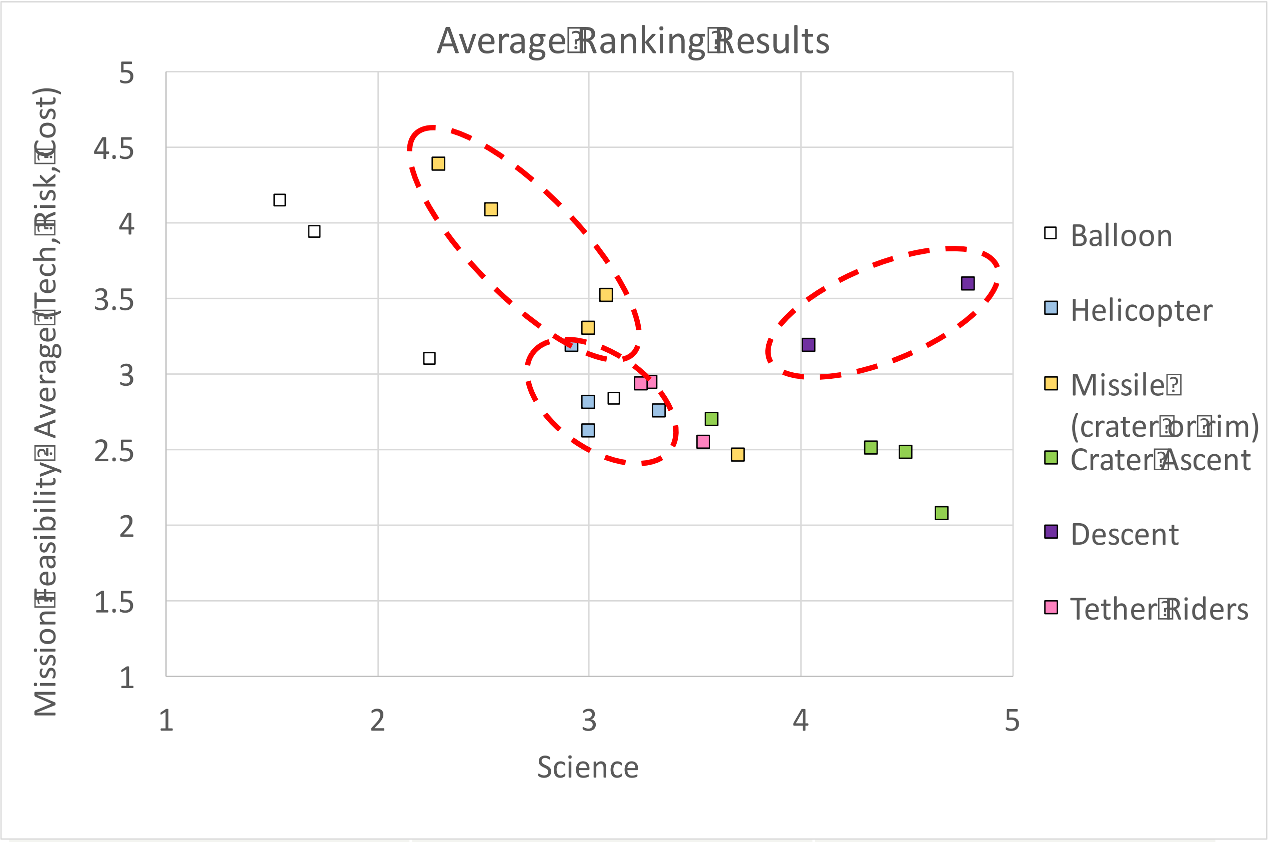


Contribution	DV [m/s]
Ascent	15
Boost	200
Brake	195
Hover (15 s)	55.5
Flyaway	50
Total nominal	515.5
Control	155
Total	670



Component	Mass [kg]
Payload	20.0
Avionics	10.0
Structure	10.0
Propulsive dry	14.7
Prop dry margin	3.7
Propellant	19.4
Pressurant	0.4
GLOM	78.2

Concept Rankings



Acknowledgements and POC

- **Science:** David Stillman (SwRI), Jay Dickson (Caltech), Colin Dundas (USGS)
- **Engineering:** Wayne Johnson (ARC), Larry Young (ARC), Soon-Jo Kim (Caltech), David Rosing (JPL), Joel Benito (JPL), Ashley Karp (JPL)

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